Contract NObsr-85185
Index No. SF001-03-01, Task 8100

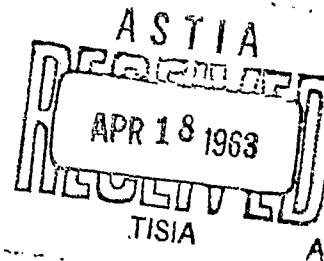TRACOR

THE DESIGN OF A PSYCHOPHYSICAL EXPERIMENT AND THE
DEVELOPMENT OF THE EXPERIMENTAL MATERIALS
TO ASSESS THE SCENICS DISPLAY

Prepared for

The Bureau of Ships
Code 689B

January 8, 1963

T R A C O R , INC.

1701 Guadalupe St.   Austin I, Texas   GR6-6601

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ABSTRACT

Problem 8 of Contract NObsr-85185 required the designing of a psychophysical experiment to assess the advantage of the SCENICS display over conventional two-dimensional displays.

An a priori method for assessing the relative merits of two-dimensional displays and the three-dimensional SCENICS display is discussed, along with the physical fact (binocular parallax) that underlies the SCENICS method.

Next, an empirical (psychophysical experimental) method and its rationale is explained, and the completed status of Phase I is noted. The methods and pitfalls of analyzing the experimental data are discussed.

Finally, it is now recommended that the outcome of the work and analysis reported here be:

1. The carrying out of the psychophysical experiment as described.

2. The search for and study of methods to apply the expected measured advantages of the SCENICS display to various detection equipments.

THE DESIGN OF A PSYCHOPHYSICAL EXPERIMENT AND THE DEVELOPMENT
OF THE EXPERIMENTAL MATERIALS TO ASSESS THE SCENICS DISPLAY

INTRODUCTION

This final report under Contract NObsr-85185 on Problem 8 which is Phase I of the SCENICS display problem, describes the present status of the problem and how it got there. It begins with a discussion of the advantages and limitations of current sonar displays and shows how, logically, the SCENICS display should yield a "display gain," and hence a system performance gain. Phase I, is, in fact, the setting up of an experiment to assess empirically the SCENICS display gain.

The emphasis throughout, implicit and explicit, is on the moment of interaction between display and operator when the operator is trying to make an <u>initial classification</u> of "target." A sonar-plus-operator system has, of course, a variety of operational functions, but most of them will not be germane to this report.

The concentration of attention on the moment of initial classification makes it possible to study carefully exactly the function that SCENICS is designed to carry out: to make the recognition of signals in background noise an easier task for an operator. Easier is used in the sense of "earlier," or "at greater range," or for "weaker signal strength" at no increase in false alarm probability (false alarm rate).

Next, the experimental design is briefly described and there are short discussions about expected results and possible applications of the SCENICS technique to other types of equipment displays.

RATIONALE

Data acquired by sonar equipments are typically displayed visually to an operator on some two-dimensional surface, e.g., a

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PPI, an "A" scan, the paper of a recorder, or some other such area. Most sonar systems also use an auditory display, a loudspeaker or a pair of earphones in parallel, which is "monophonic" and so is also lacking in spatial characteristics.

One of the main functions of sonar systems (including the operator) is to make an <u>initial classification.</u> Ordinarily we speak of the <u>search</u>, <u>detection</u>, and <u>target classification</u> functions, and so on, in which the operational function of making an initial "target" classification and determining range or time and bearing is included. In this report, however, normal search and detection functions are not immediately affected and hence will be bypassed to permit a more nearly definitive treatment of the crucial initial classification function. It ought also to be said that by initial classification we mean to imply something closely akin to that function often called <u>signal detection</u>. An initial classification occurs, then, when an operator reports that a possible target signal has been detected, and that it has a certain bearing and range, or was on a certain bearing at some specific time.

Other things being equal, the detection and classification of a target-of-interest will be more useful if it occurs "earlier" in time or what amounts to the same thing, at a greater range. There are, however, certain conditions, both physical and psychological (or psychophysical), which set practical limits on the range of initial classification. As only two physical examples from many such conditions:

1. Cavitation limits the amount of power which can be radiated by an active sonar.
2. There is some practical limit to the time we can devote to acquiring and storing data ("integration" time).

An example of a psychological limit is seen in the phenomenon of masking, whether visual or auditory, for again if other things

are equal the operator's detection of a signal in noise is limited
by his ability to "separate" the signal from the noise. The
accurate way to speak of this is to say that we may discriminate
between data that are signal generated and data that are noise
generated, but, when we fail to discriminate, the signal is masked
by the noise.

The typical, conventional way to process data is with both
signals and noise together in a single channel. Indeed the very
essence of the sonar problem is in the fact that the signals and
noise are mixed, and we must try to identify which is which, that
is, to separate them. Let us examine the case in which data are
displayed in the typical, two-dimensional way.

Leonardo da Vinci long ago showed that to depict (paint) a
three-dimensional scene on a two-dimensional surface did violence
to certain relations between objects, that considerations of
parallax were particularly onerous in cases of interposition. His
analysis of the situation is illustrated in Figure 1. The illustra-
tion makes it clear how we can see "around" objects which stand
between our eyes and some other object or surface. If one wishes,
as Leonardo did, to paint such a scene, it is quickly discovered
that on a two-dimensional surface we lose the ability to see
"around" near objects.

In Figure 2 we see that for a scene made up of two objects,
a and a_1, to be accurately depicted on a surface, $\underline{PP'}$, we would
need a certain separation between the painted objects for the left
eye and a different, in this case greater, separation for the
same objects for the right eye. We obviously cannot do this and
draw only the two objects. It is precisely this difficulty, the
limitation on our ability to divide the data of the scene between
the eyes in a natural way, that produces the unrealistic effects
we see in certain paintings, for example the peculiar way that
painted eyes seem to "follow" us as we shift position in front
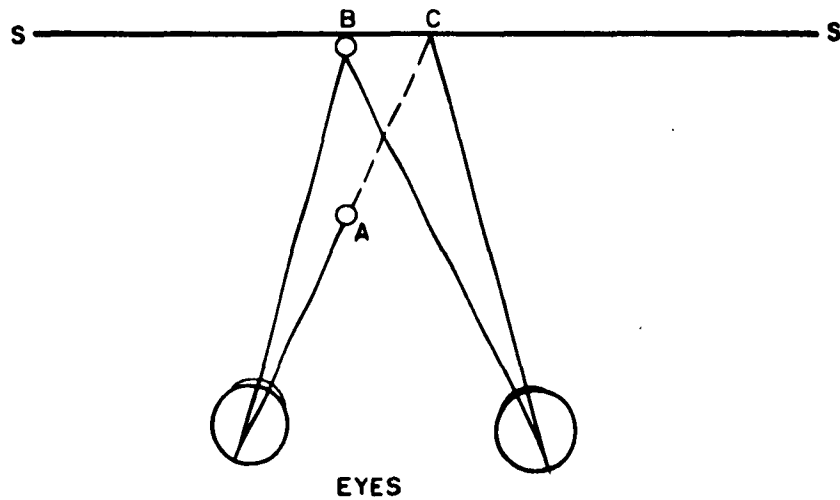
Fig. I - ILLUSTRATION OF THE ABILITY WE HAVE, WITH
TWO EYES, TO SEE ALL OF THE SURFACE SS'
EVEN THOUGH THERE IS AN OBJECT A
INTERPOSED BETWEEN.
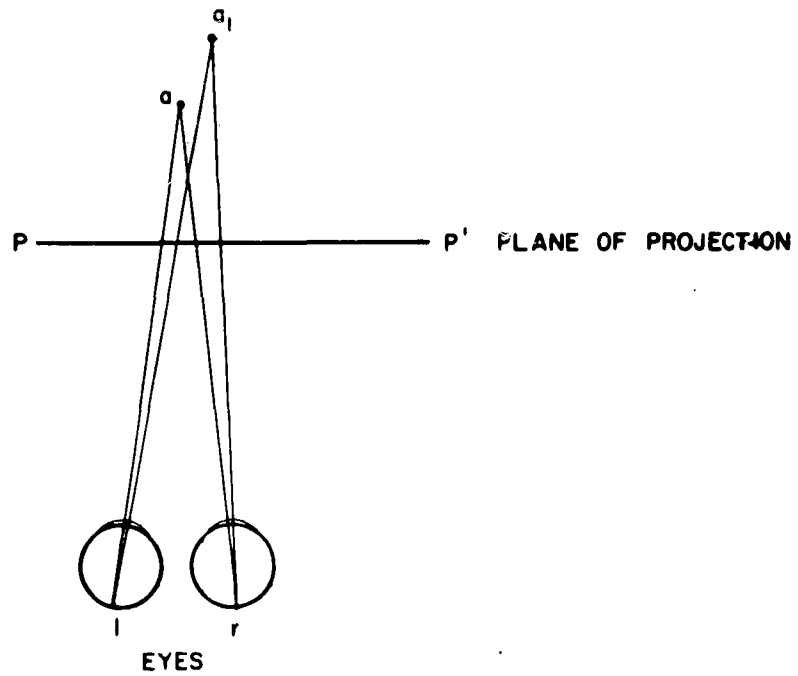
Fig. 2 - DEMONSTRATION OF BINOCULAR PARALLAX

of a picture. Theoretically, then, we would be better off, with respect to discriminating objects in space (like submarines in the ocean or aircraft and missiles in the sky), if we used two separate and independent channels to acquire and process data for presentation to two eyes (or ears) in a "natural" fashion.

Various stereoscopic and stereophonic methods have been proposed, and some of them tried, to accomplish this purpose, but in general they have suffered from having high costs (two whole channels instead of one) or from lack of enough distance between receivers, and the like. It seems, then, that it would behoove us to devise a method having the advantages of a stereoscopic system, but without the disadvantages of high cost, and so on.

The display of signal-plus-noise data in three dimensions, especially data acquired and processed in a single channel, must be shown to be advantageous. The use of three-dimensionality for its own sake is not enough; the measure of advantage can be expressed as an effective gain in signal-to-noise between a system without a 3-D display and the same system with such a display. However, this measure may be later found to be misleading or incomplete when used to express the increased effectiveness of the SCENICS display for initial classification which is after all its principal expected advantage. Because this is true, the gain of a 3-D display must be assessed independently of any real, single system. There are two kinds of assessment:

1. Logical or a priori
2. Empirical.

METHODS OF ASSESSMENT

Let us first consider an a priori method.

As stated before, sonars have among their operational functions the making of an initial classification, at a measured range, and a determined bearing. Data, therefore, when acquired by active sonars, are "tagged" with respect to range and bearing.

Passive sonars will tag data with respect to bearing only or bearing and time. Both types of sonar will have some form of display for the "tagged" data and, then, the major task of an operator is to make initial classifications, that is, to discriminate possible signals arising from targets-of-interest from the masking noise which is always present and, when such an initial classification is made, to identify its spatial position by noting the presumed target's bearing and range or bearing and time. A shortcoming of some of the current and nearly all of the older sonar equipments is that they have no way to store data adequately and present the results, in the active case, of several transmissions and returns, although in the passive case, recordings on paper of several minutes or hours of "listening" is possible. Systems which have some capability for storage present us with an opportunity to take advantage of the human ability to utilize parallax for the separation of objects in visual space and to use the ability to perceive spatial target tracks.

Assume a passive sonar system with a hundred fixed beams which are sampled once each second. The equipment gain is adjusted so that when noise alone is present the outputs of 10% of the beams will, on the average, make marks on the display. In a particular beam and on a particular "look" if the noise exceeds this threshold a mark will be recorded, stored and displayed. Assume further that the storage has enough capacity to retain three hundred seconds of data for each of the one hundred beams. This gives us some numbers to work with.

Let
$$m = \text{marking density for noise, and}$$
$$m' = \text{marking density for signal.}$$

The density of marking is related to power. The marking density does not have a linear relation to power, however, nor to signal-to-noise ratios. The relationship will be analytically determined at a later date. Therefore, for input powers

$$10 \log \frac{m'}{m} = \text{marking density ratio}$$

We have assumed m = 0.1; let us also assume m' = 0.1, i.e. equal probability of signal or noise marking.

Thus, the input to the display has S/N = 0db, but for the display output, where the two marking densities are additive,

$$\frac{N + S}{N} = 10 \log \frac{m + m'}{m} = 10 \log \frac{0.1 + 0.1}{0.1} = 3 \text{ db}.$$

Three db is very seldom a large enough change of density ("brightening") to permit an operator to make an initial classification, and in fact it is commonly accepted that 4 db is necessary for 50% initial classification (often called "threshold of detection"). But that figure is derived from an average over "single looks," and we have assumed that we can store 300 seconds of data or 300 separate looks at each of 100 beams. The display area, 100 x 300, then, has 30,000 bearing-time bins which may be displayed at once and for this example in these bins we will have 3,000 randomly appearing marks which come from noise alone.

For simplicity let us further assume that the signal appears randomly, which is the worst possible case, at the already assumed 0.1 density, in a particular beam, i.e., with zero bearing rate. If we examine any bearing other than the bearing containing the signal, we will expect to find an average of 30 marks which are generated by noise alone, but on the bearing which contains the signal the expected number of signal-plus-noise marks, again on the average, is 60. As indicated previously, however, this increment in density only amounts to 3 db and is usually not perceived. A sufficiently large electronic computer given time enough to scan the bearing-time display area bin by bin and integrate over every possible track would sooner or later find the

track we have hypothesized. If, however, we can take advantage of an already available "computer," the operator, we ought still to be able to do it, and more quickly and cheaply. The method for doing so follows.

Instead of a single storage for 300 seconds x 100 bearings, assume two, each one storing 150 seconds x 100 bearings (the same amount of data). In the first storage put data which will be displayed to the right (starboard) eye alone and in the second put data which will be displayed to the left (port) eye alone. For the first beam-sampling period the data are stored in the first storage, for the second period in the second storage, for the third period again in the first, and so on, so that data from "odd-numbered" periods will be in storage one (starboard) and from "even-numbered" periods in storage two (port). Now search for coincidences. For example, if in a certain odd-numbered period in a particular beam there was a data mark stored and displayed, was there also a mark in that same beam in the even-numbered period that succeeded or preceded it? In other words: "What is the joint probability that marks will be displayed in the same beam in two successive sampling periods?" In the conditions we have assumed the joint probability if noise alone is present is 0.1 x 0.1 = 0.01. In other words, in the 300 sampling periods we have stored, 150 in one storage and 150 in the other, on any given bearing we can expect to find, on the average, three such pairs of successive marks. (This obviously is true for the even-odd sequence as well as the odd-even, since the designations are arbitrary anyway.) If we look for such pairs in the bearing which has the signal, how many such pairs should we expect? Remembering that the density of $m + m'$ is twice the density of m, should we then expect 6 pairs? That is, in a bearing having noise alone there will be 30 marks and 3 pairs, so in the bearing having the signal we should perhaps expect 6 pairs out of the 60 marks, or still a ratio = 3 db. This reasoning is fallacious.

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The joint probability for a paired sequence of $m + m'$ is $0.2 \times 0.2 = 0.04$; therefore, over 300 sampling periods we should expect to find not six pairs, but twelve. Further, the output marking ratio may be computed as

$$= 10 \log \frac{(m + m')(m + m')}{(m)(m)}$$

$$= 10 \log \frac{0.2 \times 0.2}{0.1 \times 0.1} = 10 \log \frac{.04}{.01} = 10 \log 4$$

$$= 6 \text{ db}$$

Theoretically, then, if we can but identify pairs easily we shall have realized a gain from 3 db to 6 db, under the assumed noise and signal marking densities. As we have said, a density change of 4 db yields 50% classification (detection) in a typical sonar display recognition differential. Thus, in this example the "flat" display would not yield a detection but the SCENICS type display would.

The method we call SCENICS permits us to identify these pairs of marks. SCENICS is constructed to shift the bearing data presented to the right eye leftward a predetermined number of bearing widths, say five for a display 100 bearing bins wide. The result of the shift is to bring the noise data presented to the two eyes into random coincidence, visually, while the $m + m'$ data marks, since they come from one or a few time-related bearings, will be in regular coincidence. A track of $(m + m')^2 \times$ number of sampling periods, L, data marks will then appear at a determinate place in visual depth, while the noise will appear scattered in visual depth in a random fashion.

The foregoing constitutes the basic a priori analysis. The other, empirical, evaluation is embodied in the experiment to be

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carried out as Phase II of the over-all SCENICS problem and is
subsequently described in this report.

A mathematically similar process to the a priori evalua-
tion already described is carried out by the storage and presenta-
tion of 5 successive simulated transmissions and returns in the
NEL CHARACTRON display. Here the reliance is on the consistent
appearance of marks displayed in a background density of noise of
about 10% (2%, on the average, per transmission). Again, however,
the joint probability, given certain noise and signal conditions,
that a particular set of affairs will occur in sequence may be
computed, and an effective gain determined. In the passive sonar
case chosen for discussion here with respect to SCENICS such other
conditions as differences in intensity, frequency content, and so
on, have not been considered. In an operational sonar such things
would not be left out because of the additional information they
would contain for classification purposes, and later phases of
the SCENICS program should explore them.

PHASE II OF SCENICS

The requirements to simulate the SCENICS display are simple.
We need two display surfaces, one for the left eye and one for the
right, a means of getting binocular fusion, and a data handling
method which controls the interocular parallactic relations. The
simulation method chosen uses a motion picture projector, a ground-
glass screen, and a pair of prisms to achieve binocular fusion. A
computer was used to generate and print the data which are simu-
lated "noise alone," and "noise-plus-signal" in an appropriate
track. Control was maintained over the density of noise marks and
of noise-plus-signal marks, and means provided for the control of
binocular parallax.

The computer-printed visual display fields are photographed
with a movie camera and are to be projected for observers at one
frame every two seconds. Each new projected frame has a new line

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of data entered at the bottom with the oldest line at the top
dropped off.   Count of frames will be kept so that when an observer
indicates that he believes he has classified a target track, the
particular frame where he makes his identification is known.   A
check is possible, also, on false classifications since the track
position is known, and if observers indicate a track where none
exists the call is obviously a false detection.   The means exists,
too, for checking such false detections for their apparent "reality,"
that is, whether conditions are just right in areas of noise alone
so that a track-like sequence is in fact present.

Phase I of Problem 8 is very nearly completed.   We have
printed out two sets of tracks for each of the noise and signal
conditions indicated in Table I.   Each condition is printed in
such a way that when photographed it may be projected for viewing
in either of two conditions, the first is "flat" as in the typi-
cal bearing-time plot, and the second with parallax introduced to
generate visual depth.   Only the density of the signal is indi-
cated in the table, but the printed target track, to be realistic,
is printed out at the density of noise plus signal.

There are forty N by S combinations, and the N + S/N ratio
for the three-dimensional case has been calculated and entered in
the appropriate box for each combination used.   The ratio in db
for the two-dimensional case may be easily obtained by dividing
each ratio for the 3-D case by two.   It should be firmly kept in
mind that N and S stand for marking densities, not acoustic
power.

Each combination is used twice to provide opportunity for
making observations in different random noise backgrounds at the
same densities and to permit target tracks in different bearings
to be used.   Each one of the 2 x 40 = 80 tracks is printed twice
to give each track a "flat" and a "3-D" appearance.   There are,
therefore, a library of 160 film strips for observers to use.

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TABLE I

COMBINATIONS OF SIGNAL AND NOISE MARKING DENSITIES PRINTED BY

COMPUTER FOR THE SCENICS SIMULATION

NOISE \ SIGNAL	.05	.10	.15	.20	.25	.30	.35	.40
.10	3.52	6.02	7.96	X	X	X	X	X
.20	1.93	3.52	4.86	6.02	7.04	X	X	X
.30	1.33	2.50	3.52	4.44	5.26	6.02	X	X
.40	1.04	1.93	(1) 2.76	3.52	4.22	4.86	X	X
.50	.83	1.58	2.28	2.92	3.52	4.08	4.61	5.10
.60	X	1.34	1.93	2.50	3.01	3.52	4.00	X
.70	X	X	1.67	2.18	2.65	3.10	X	X
.80	X	X	1.49	(3) 1.93	(2) X	X	X	X

In Table I those combinations of noise and signal that are crossed out are not used. The combination marked (1), which is used, has a noise marking density of 0.40 and a signal of 0.15, therefore, according to the previously stated equations,

$$\frac{N + S}{N} = 10 \log \frac{p(0.40 + 0.15)}{p(0.40)}$$

$$= 10 \log \frac{0.55}{0.40} = 10 \log 1.375$$

$$= 1.4 \text{ db, approximately}$$

which holds for the two-dimensional case, while

$$\frac{N + S}{N} = 10 \log \frac{(0.55 \times 0.55)}{(0.40 \times 0.40)}$$

$$= 2.8 \text{ db, approximately}$$

for the three-dimensional case. The combination marked (2) is not possible since N + S = 0.80 + 0.25 is greater than 1.0. In the case of the combination marked (3), N + S is exactly 1.0. The noise marking density is 0.80, however, which is quite high, and so it is necessary to answer empirically the question of whether a track can be discerned in such a cluttered (noisy) background. For the 2-D case, with these noise and signal densities, 10 log N + S/N = 1 db approximately (0.97 db); and in the 3-D case, 10 log N + S/N = 2 db approximately. Nonetheless, the target track will have a mark recorded in almost every bearing-time bin in which it falls (we can expect, even though the calculated probability of a mark is 0.8 + 0.2 = 1.0, that every now and then a mark will by chance not appear) and so it may be discriminable in spite of its apparently low ratio. The experiment to be carried out as Phase II will tell the tale. The combinations of N and S that are not used, in addition to

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those in which N + S is greater than 1.0, are those combinations
like N = 0.1 and S = 0.4 where it could be expected that the track
would be perfectly obvious since 10 log N + S/N = 14 db for the
3-D case, and those like N = 0.8 and S = 0.05 where no one could be
expected to discern the track anytime since 10 log N + S/N = 0.4 db.

A brief outline of the psychophysical experimental program
to be carried out in Phase II is included here for clarity and
continuity.

Employing the 160 film strips described previously, we will
require 12 observers to attempt to find the tracks displayed. Re-
cords will be kept for each observer in each condition which will
indicate a "hit" or a "miss" or a "false alarm". When a <u>hit</u> is
recorded, the frame number will be noted to show where the track
is and how much of the track (in the case where an initial classi-
fication is made before the track extends over all the time bins
available in the display) is displayed when the hit is made. From
these data a limenal signal-to-noise ratio will be calculated for
an assumed "normalized," false alarm rate, if it proves possible.
In any case, at the very least, a measure like the commonly used
"recognition differential" can be derived. Not until the empirical
data are actually in hand can a decision be made about which way
to go. Let us try to see why. Suppose, for an example, that 9 of
our 12 observers get hits on the stimulus combination p(N) = 0.5
and p(N + S) = 0.7, which gives a calculated 3-D S/N ratio of
2.92 db, but only 5 of the 12 hit on the p(N) = 0.6 and p(N + S) =
0.9 which has a 3-D S/N ratio = 3.52 db. On the other hand, be-
cause the distribution of noise marks is a random affair, let us
further suppose that the false alarms recorded for the first in-
stance, where the density of N + S = 0.7, is <u>greater</u> than for the
other, where the density of N + S = 0.9. Some method must be
found for reconciling these inversions (if they do in fact appear
in the data) and some kind of <u>base line</u> false alarm rate , and 50
per cent detection-of-targets, caused to emerge from the data.

Suppose further that the results of Phase II show an "initial classification" for a particular N + S/N ratio. An examination of Table I will make evident that there are several powers of noise (noise densities) and powers of signal that yield the same ratio. But it can be anticipated with confidence that the false alarm rates for different noise densities but equal ratios will be different. Therefore, we must try to find for the SCENICS display the noise density, at the N + S/N ratio which yields a signal detection probability of 0.5, having the lowest false alarm rate.

The difference of criterion is necessary and desirable because an _initial_ _classification_ is made from the SCENICS display in exactly those circumstances where the standard display yields only detections with an uncertain probability of false alarms. The whole sequence of sonar operational functions is further along, in other words, when an operator using SCENICS makes a "call."

For our present purposes _input_ _S/N_ in the usual sense is not pertinent because the computer printed data yield an _output_ N + S/N of densities at the display. Out of the experimental results a 50 per cent initial classification will be found, however, and the false alarm rate at that point will be computed or, at worst, estimated.

The results to be expected from the experiments have already been implied in the foregoing. Theoretically, it can be argued that the best we can expect SCENICS will do is to double, in db, the output N + S/N ratio over that for the 2-D case. On the other hand, because of the longer "integration time" permitted by the storage and simultaneous display of many seconds of data from passive systems, or several transmissions and returns in active systems, a gain of some amount which is not predictable a priori will be realized. That is, the human ability to perceive

spatial patterns in a three-dimensional visual space will give us
an added gain which can only be ascertained empirically. On that
account, then, the over-all gain from SCENICS may well be greater
than the calculated doubling in db.

A real necessity exists for finding these relations, since
the limenal signal-to-noise ratio has in practice been defined
for a given decision(detection) device (sonar-plus-operator sys-
tem) as that input S/N ratio which produces a probability of
single event detection of 0.5 when the threshold (gain) has been
adjusted to have the system operating so that the masking noise
yields an unspecified false alarm probability. It is precisely
the fact that false alarm rate has not been consistently taken into
account in previous sonar and display evaluations that there exists
no common ground for comparison between displays. It is clear
that an implicit attempt was made, however, because of the use of
the common rule-of-thumb to adjust the gain to set the noise so
the "snow" (or "grass") is just comfortably visible. Therefore,
while false alarm rate was not set explicitly, it was under
practical constraint. The assessment of the SCENICS display will,
on that account, endeavor to make use of a specified false alarm
rate, for it is clear that as soon as a threshold is chosen for
a decision device a false alarm rate is absolutely determined,
provided that there is some specified power of noise also. For
example, in sea state 1 the threshold can be set lower than it
can be set in sea state 5 to yield the same false alarm rate (or
to have the "snow" just comfortably visible). Also, in the weaker
noise, other things being equal, a weaker signal may be detected.
However, the crucial point is that once a false alarm rate is
in fact determined by choosing a threshold setting then the signal
power which, under the prevailing noise conditions yields 50%
detections, may be determined, i.e., the input S/N ratio which
produces a probability of signal detection of 0.5 is to be meas-
ured when the threshold has been adjusted for the prevailing noise
conditions to yield a specified false alarm rate.

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However, as previously pointed out, the commonly used detection criterion is a secondary part of the SCENICS display function and a different criterion must be used to measure the effectiveness of the SCENICS classification capabilities. Obviously, this criterion must invoke desirable false alarm rates under varying conditions of alertness.

Collaterally with the numerical results of the Phase II experiment, some plans for methods of application of the SCENICS display to specific sonar equipments need to be made. Problems of data storage and processing can be intelligently handled only after the best N + S/N output ratio with a desired false alarm rate is known.

The variability in N + S/N values with which operators can adequately deal will also affect the design of systems for their ultimate optimal use. Since there is every reason to expect a substantial gain in output N + S/N, the SCENICS display should ultimately be directly compared with alternative displays to determine empirically the best display for a specific detection system.

Although the present objectives of SCENICS are entirely directed at sonar system applications, its display processing gains to be measured under Phase II can be readily applied to electromagnetic detection and tracking systems.

SUMMARY AND RECOMMENDATIONS

The psychophysical experiment has been designed and the preparation of the test material (film strips) is almost complete.

An a priori method for assessing the relative merits of two-dimensional displays and the three-dimensional SCENICS display has been developed. This method will permit the results of the psychophysical experiment to be applied analytically to new or existing active and passive sonar equipment designs.

The results of the psychophysical experiment will demonstrate the potential "display gain" which can be realized by providing a SCENICS type display to any single channel detection system.

It is recommended that the psychophysical experiment be performed as presently designed and that the resulting data be used to analytically show the performance improvement for several sonar systems if they were fitted with a SCENICS display.